

The Moving Vessel Profiler (MVP) - a Rapid Environmental Assessment Tool for the collection of water column profiles and sediment classification

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Introduction

The Moving Vessel Profiler (MVP) has been developed as an automated data collection tool that can be used from vessels while underway. It has been effectively used to collect mid-water oceanographic information to support science and hydrographic survey operations.

The Free Fall Cone Penetrometer (FFCPT) has been developed as a geotechnical measurement instrument that can be deployed in a stand-alone (self recording) mode or from a slip ring equipped free-fall winch with the capability of real-time telemetry.

The MVP and the FFCPT have been successfully integrated to arrive at a novel and tremendously efficient system to provide water column profile data and grain size analysis of the seafloor in support of numerous marine activities including science, hydrographic and naval applications. The MVP with FFCPT can make these measurements while the vessel is underway at 4-8 knots. The ability to collect this data makes the system a useful Rapid Environmental Assessment (REA) tool.

This paper will describe in detail the MVP, FFCPT and the integration of the technologies. Some REA data collected during trials is then presented.

Moving Vessel Profiler (MVP) System Description

The Moving Vessel Profiler (MVP) is a computer controlled winching system that can deploy and recover a sensor from a ship that is underway. The system is controlled by a computer that accepts input from the operator, input from the vessel for vessel speed and position, and fish depth to execute a safe mid-water deployment. After achieving the desired depth the computer automatically applies the brake on the winch system and recovers the fish back to the towed position behind the ship [1].



Figure 1: Moving Vessel Profiler Family of Systems

The system can be used to measure a variety of parameters in the water column and is available in a number of sizes as illustrated in Figure 1. The numeral component of the system name represents the depth of a mid-water cast achievable at a vessel speed of twelve (12) knots. Figure 2 illustrates the various components of the MVP200 system. A critical requirement is a baseline sensor that includes a pressure sensor. Typically baseline sensors are a “Conductivity, Temperature and Depth (CTD)” sensor or a direct reading “Speed of Sound and Pressure (SV&P)” sensor. Either of these sensors can be installed in the tail of the highly stable Free-Fall Fish. If additional water column parameter measurements are required then the baseline sensor can be augmented with a variety of additional sensors including a Fluorometer, Laser Optical Plankton Counter, Dissolved Oxygen, Optical Backscatter, Radiance and Irradiance. In order to deploy the multiple sensor payload, a Multi-sensor Free-Fall Fish must be used.

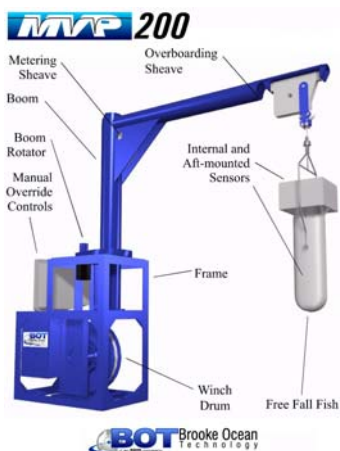


Figure 2: Labeled Illustration of the MVP200

An ocean data profile is collected during the nearly vertical free fall and then if desired during the recovery along the catenary defined by the tow cable as it is deployed from the underway ship, as shown in Figure 3.

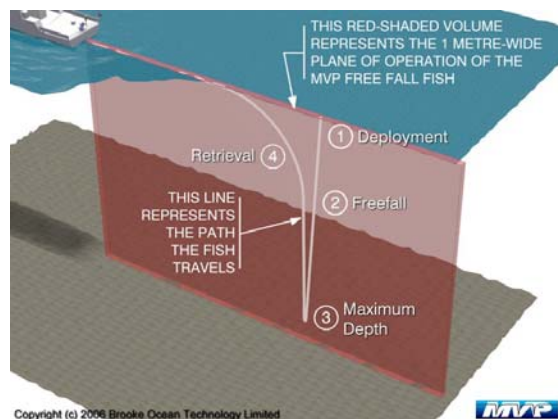


Figure 3: Illustration of the Deployment Catenary Shape

The control software presents the users with a trace of fish depth and bottom depth for monitoring operations. The user has an abort switch (both software and hardware) that can be used to abort the cast.

Deployment of MVP's fish while additional items are deployed from the vessel can be achieved. Several operators have deployed side scans, towed fish, and acoustic arrays while performing MVP casts.

Free Fall Cone Penetrometer FFCPT System Description

The Free Fall Cone Penetration Test (FFCPT) is an instrument designed for the rapid geotechnical profiling of subaqueous sediments. It was developed based on proven piezocone penetration test (CPT) theory and algorithms. The instrument is designed to free fall through the water column, eventually impacting the seabed, recording penetration data at a high sample rate (2 kHz). This permits high resolution characterization of the sediment layering and material properties such as grain size and undrained shear strength. Penetration depth below the seabed is governed by the terminal velocity in the water column and the seafloor sediment characteristics. Penetration depths of 2 – 3 meters in soft clay are typical.

The FFCPT is 88 mm (3.5 in.) in diameter, 1.8 m in length and weighs 115 lbs (in air). It is modular in nature (as shown in Figure 4) and carries three sensor types for the collection of geotechnical data – accelerometers, pressure sensors and an optical sensor. The accelerometers and nose pressure sensor measure deceleration and dynamic pore water pressure respectively. The tail pressure sensor is used to measure hydrostatic pressure, which permits monitoring of the instrument velocity during free fall. The optical sensor is used to discern the sediment-water interface and is particularly useful to detect the presence of fluid mud suspensions.

An SV&P sensor in the bail module of the FFCPT permits the measurement of sound velocity in the water column. This increases the utility of the instrument by making the data set more comprehensive for both REA applications and mapping systems that have a basic requirement for sound speed data [2].

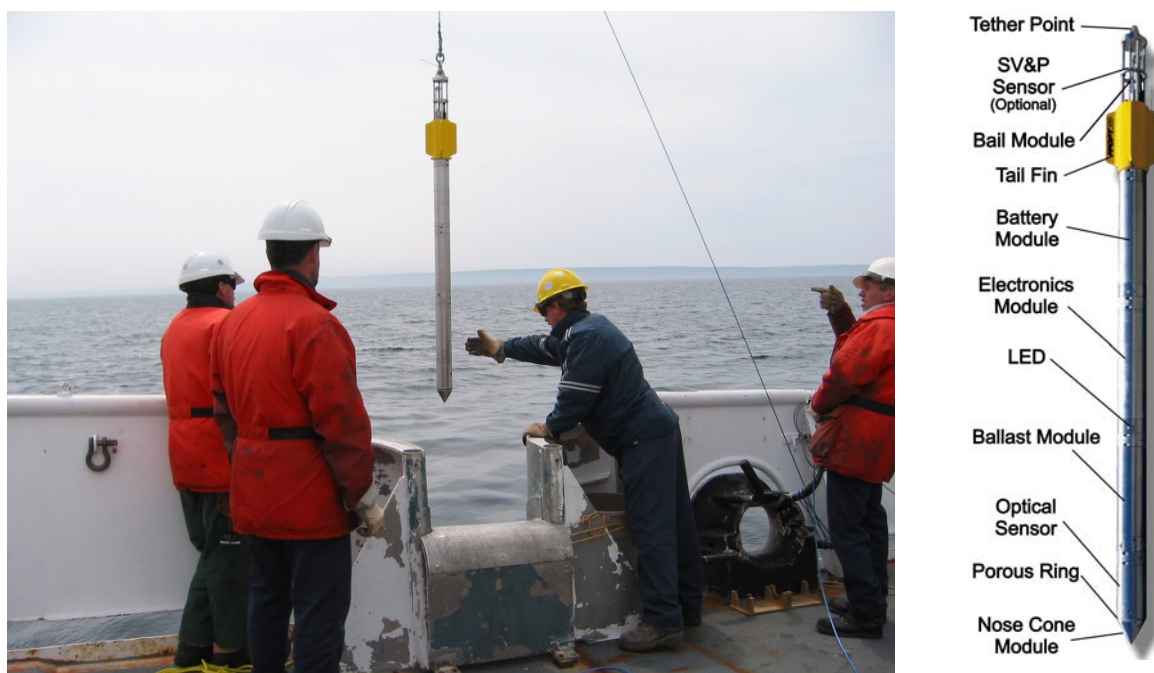


Figure 4: Photograph of FFCPT Being Deployed in Self-Logging Mode and Labeled Sketch of FFCPT

The resulting penetration record generates digital data from the sensor suite, which is used to interpret the geotechnical characteristics of the sediment tested. The resulting interpretations are presented as depth discretized profiles, similar to those obtained from conventional CPT methods. These results include dynamic penetration resistance, dynamic pore water pressure, sediment behaviour type and undrained shear strength. The undrained shear strength is calculated by two independent methods: one method uses the dynamic penetration resistance which is calculated from the accelerometer data while the other method uses the dynamic pore water pressure. These interpretations are easily performed by the FFCPT operator using custom-designed FfcptView software.

The sediment behaviour type (e.g. clay, silt, sand, or gravel) is determined qualitatively by the direct application of geotechnical analysis methods and parametric-based correlations already long established in engineering practice [3]. By plotting normalized values of the dynamic penetration resistance and the dynamic pore water pressure against each other, an empirical measure of sediment type is provided (Figure 5), based on the zone in which the data lie (Table 1). Discrete measurements at different depths are plotted as dots, colour coded as a function of depth from the seabed to the depth of penetration of the FFCPT into the seabed. The FFCPT sediment behaviour type may also

be presented as a colour coded ‘pseudo-core’ (Figure 5). Through comparison of FFCPT results with independent measurements of sediment grain size and porosity for clay, silt, and sand seabeds, Osler et al. [4] confirmed that the FFCPT accurately characterizes a diverse range of marine sediments. Figure 5 provides a sample comparison of an FFCPT pseudo-core with grain size measurements from an actual core at the same location. (To permit a comparison with the four grain size fractions in the actual core, note that two of the five FFCPT sediment behaviour types have been colour-coded identically).

Table 1: Description of FFCPT sediment behaviour types (after [3])

FFCPT Zone	Sediment Behaviour Type
1	Sensitive, fine-grained
2	Organic sediments: wood waste, peats
3	Clays: clay to silty clay
4	Silt mixtures: clayey silt to silty clay
5	Sand mixtures: silty sand to sandy silt
6	Sands: clean sands to silty sands
7	Gravelly sand to sand

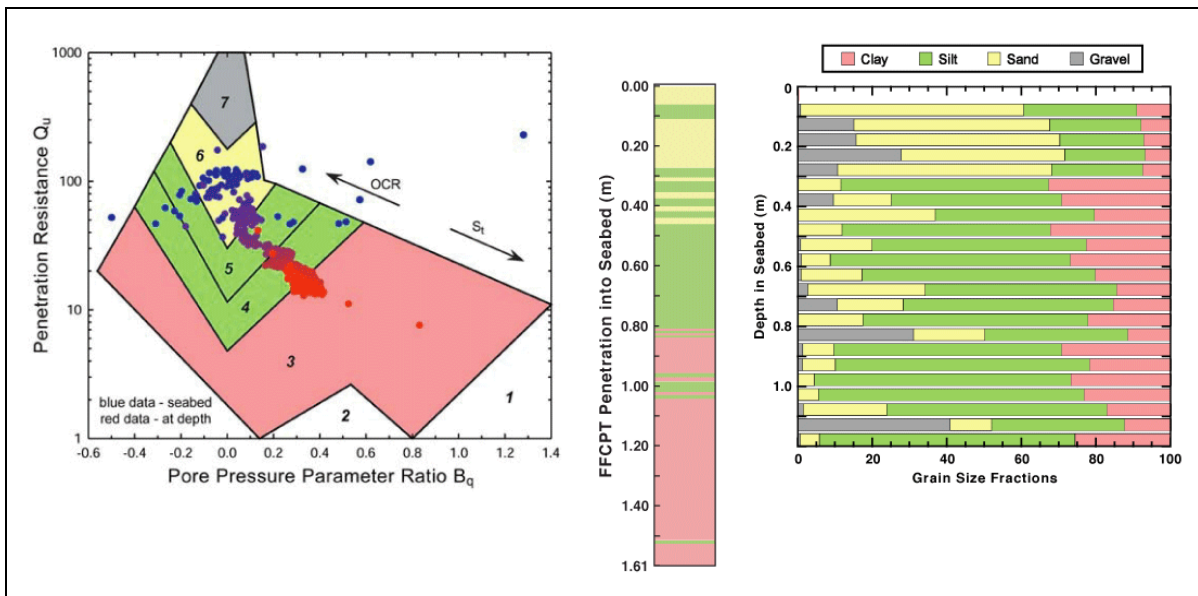


Figure 5: Left: Sediment Behaviour Type of an FFCPT Drop at a Site in St. Margaret’s Bay, Nova Scotia [2]. Middle: “Pseudo-core” of the Dominant Sediment Behaviour Type Measured by the FFCPT. Right: Grain Size Analysis of a Co-located Sediment Core, Collected by the NRV Alliance. The seabed has a Surficial Layer of Sand Underlain by Finer Grained Material.

Integration of the Moving Vessel Profiler with the Free Fall Cone Penetrometer

The FFCPT has been integrated with the MVP to create an efficient platform for the collection of geotechnical data from a vessel that is either on-station or underway. The requirement to deploy the FFCPT led to the development of a modified overboarding sheave, referred to as a line puller. A load cell has also been added to the MVP to monitor pullout loads.

To prevent rotation of the FFCPT while under tow, the tail fin has two enlarged fins. This permits a stable tow and does not adversely affect the in-flight dynamics of the instrument during free fall. Deployment of the FFCPT and the standard free-fall fish use the same electro-mechanical tow cable.

The seabed geotechnical and water column sound velocity data can be downloaded and viewed after each successive cast. This permits near real-time feedback on seafloor characteristics and mid-water oceanography. The data is also stored on non-volatile flash memory.

The FFCPT has been deployed underway at vessel speeds ranging from 4 to 8 knots [2]. After free-fall and penetration as depicted in Figure 6, the instrument is extracted from the seabed by the MVP brake. A near-vertical pullout force is exerted by the catenary that the tow cable forms in the water column as a result of cable drag forces. The instrument is subsequently retrieved through the trajectory shown in Figure 6 while the collected data is written. Experimental work to date has provided evidence that pullout load decreases as vessel speed increases as a result of these cable drag forces [2].

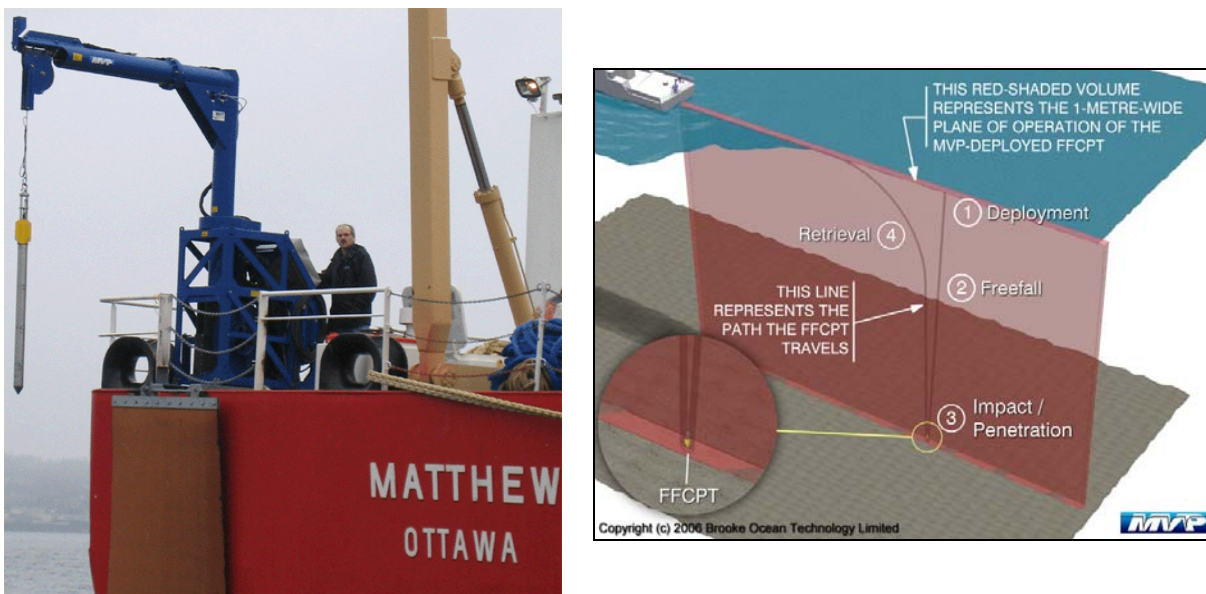


Figure 6 – FFCPT Deployed from MVP200 on CCGS Matthew and the Approximately 1m Wide Plane of Operation of the MVP Deployed FFCPT.

Moving Vessel Profiler and Free Fall Cone Penetrometer Applied to Military Rapid Environmental Assessment

An application for the MVP is the rapid environmental assessment (REA) of water column and seabed parameters to improve the performance predictions of ASW sonar systems. These predictions are often based on historical databases of bathymetry, water sound speed, and bottom properties and can be prone to error. To illustrate this point, acoustic transmission loss (TL) measurements are compared with predictions from a numerical model with different combinations of historical and *in-situ* characterization of the environment.

The historical data includes bathymetry taken from the Geological Survey of Canada (GSC) [5] and sound speed profiles for the month of October incorporated into the WADER32 model database [6]. The *in situ* data was measured using: an echo-sounder for the bathymetry; MVP CTD casts to determine sound speed in the water column; and the FFCPT was dropped at several locations along the experimental track to determine the seabed composition. The FFCPT identified that a hard sand bottom was characteristic for most the area.

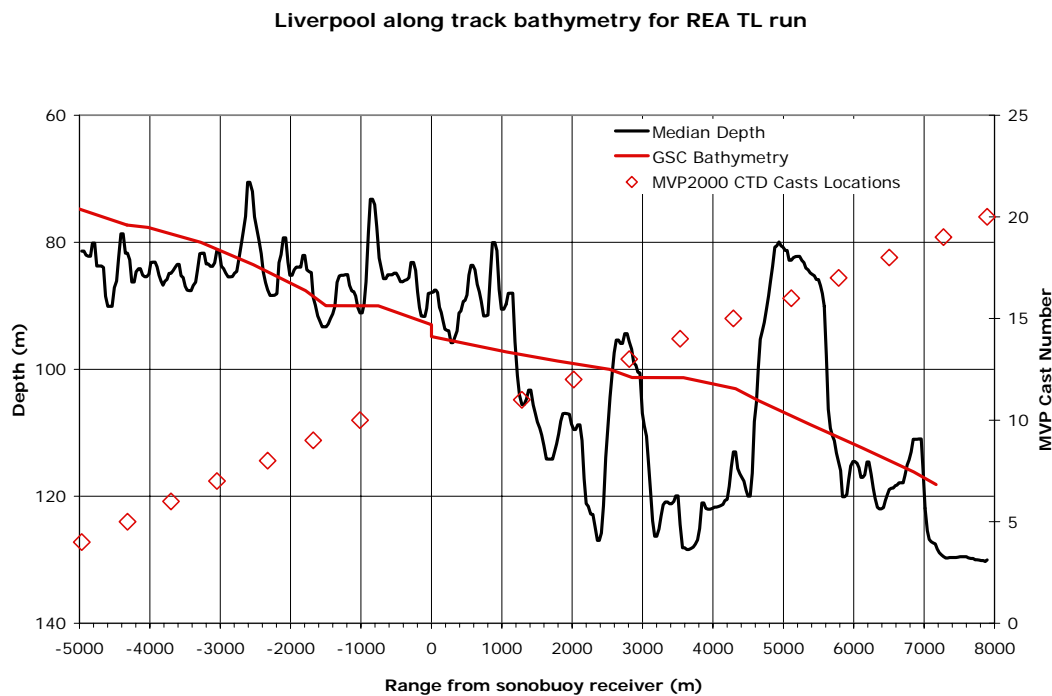


Figure 7: Bathymetry as Measured and from Geological Survey of Canada (GSC). Also Shown are the Locations of CTD Casts Plotted Versus Cast Number.

Figure 7 provides a comparison of the historical and *in situ* bathymetric data along the REA TL track. For the modeling process, the REA TL track was divided into two

sections on either side of a moored receiver. There is a “shallow” area (from about -5000 m range to 0 m range) and a “deep” area (from 0 m range to about 8000 m range). The bathymetry is far more variable than the historical data would suggest. Twenty CTD casts were obtained using the MVP while *CFAV Quest* was also towing an acoustic source at 9.5 ± 0.5 m depth. The receiver, a type 53D(3) sonobuoy, was deployed in a moored configuration at 60 m depth at location $43^\circ 55.708' \text{ N}$, $064^\circ 23.026' \text{ W}$ (off the coast of Nova Scotia near Liverpool), in water depth of 88.8 m. Due to limitations in the Bellhop acoustic propagation model, only a subset of the CTD casts were used in the TL model predictions. The “deep” area sound speed profile set consists of two profiles, from CTD casts 11 and 15 (changing at 4000 m). The “shallow” area sound speed profile set consists of two profiles, taken from CTD casts 11 and 6 (changing at -3000 m). Figure 8 indicates the significant differences between the historical and *in situ* sound speed profiles, particularly the abruptness of the thermocline and the duct between 40 and 100 m.

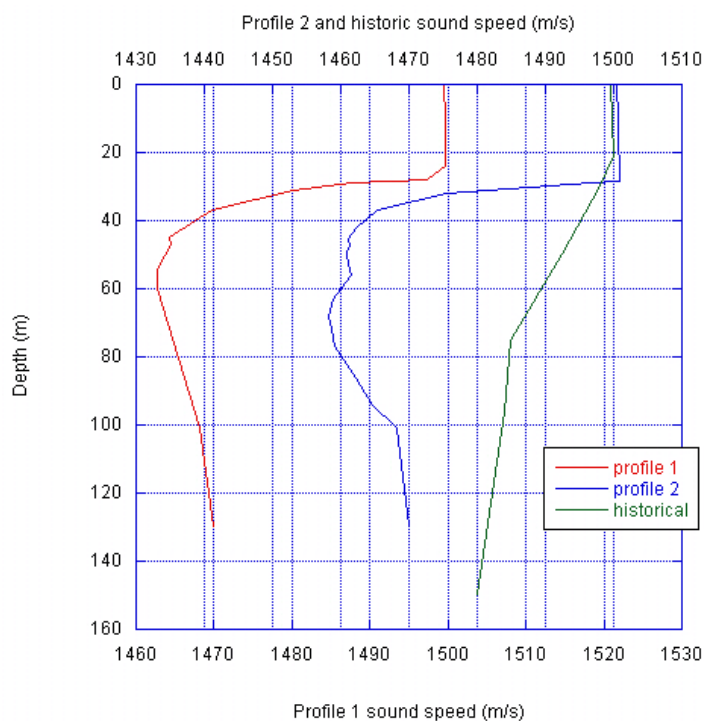


Figure 8: Deep Area Sound Speed Profiles. Profile 1 is CTD Cast 11; Profile 2 is CTD Cast 15.

(Note that the Scales for Profiles 1 and 2 are Offset)

Several modeling runs were performed to compare modeled transmission loss produced using the different sets of environmental data. Most of the modeling was done using the program Bellhop-DRDC [7], a Gaussian beam program that includes range-dependent bathymetry, sound speed, and bottom type. The bottom type is specified using the High-Frequency Bottom Loss [8] MGS province 1, a low-loss bottom with losses at 1.4 kHz from 0.2 dB to 6 dB for varying grazing angle. This was used to approximate the sandy and rocky bottom measured using the FFCPT. Sub-bottom profile images and FFCPT drops indicate sediment “ponds” in some of the deeper areas, particularly near the +3500 m and +7000 m distances.

Figure 9 and Figure 10 show the coherent TL field at 1.4 kHz calculated using Bellhop-DRDC in the deep area of the experiment, using measured bathymetry and sound speed profiles for Figure 9 and historical data for Figure 10. (Further details regarding the modeling may be found in [9]). The TL using the actual bathymetry and sound speed profiles shows both a more focused area of sound transmission between 50 m and 60 m depth (particularly around 4 km range) and greater transmission loss in the shallower water, surface to 30 m depth, past 1 km range.

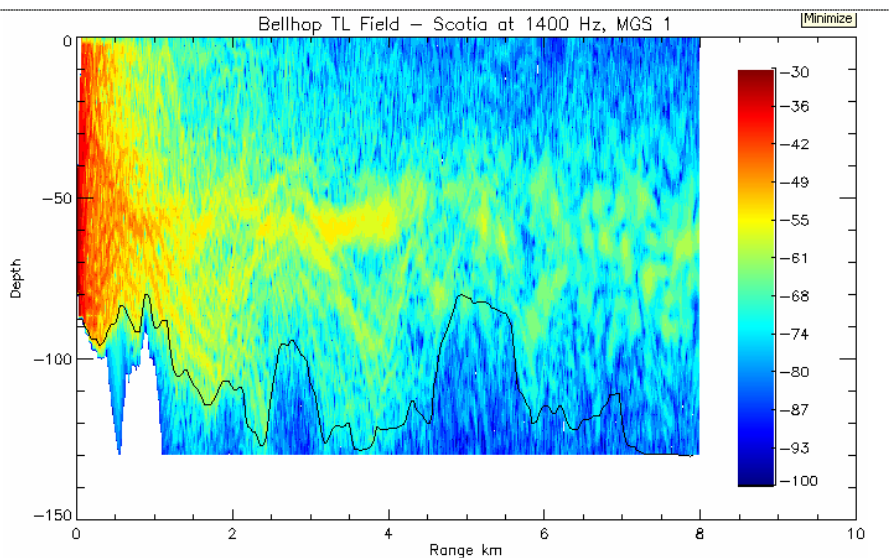


Figure 9: Transmission Loss at 1.4 kHz from Bellhop Model – Deep Area of TL Run, Using Measured Sound Speed Profiles and Bathymetry. Colour Scale is in dB re 1 m.

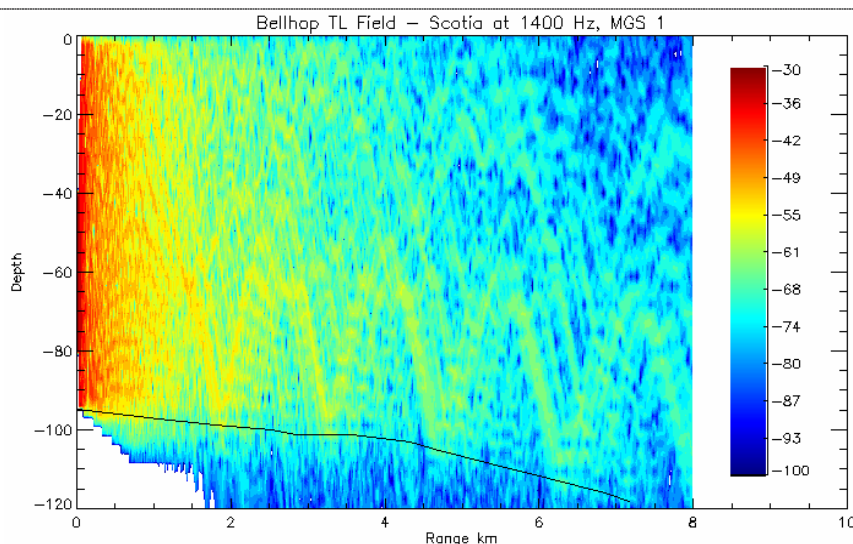


Figure 10: Transmission Loss at 1.4 kHz from Bellhop Model – Deep Area of TL Run, Using Historical Sound Speed Profile and GSC Bathymetry Data. Colour Scale is in dB re 1 m.

Figure 11 shows the modeled incoherent TL from Bellhop-DRDC for the deep area for different sets of environmental data compared to the measured data (green dots). (Further details regarding the data analysis may be found in [9]). The data fit is better for the real (measured) bathymetry and sound speed profile (black line) than for the historical (red line). The RMS model-data difference for the deep area is 4.8 dB for the measured environment compared to 6.2 dB for historical, with the mean model-data differences being 2.4 dB and 5.2 dB respectively. The model using measured data also seems to accurately reproduce the dip in TL that occurs at about 5 km range in the deep area (near the ridge), although it erroneously indicates less TL at longer range (7 to 8 km) than was found. This may be due to the higher-loss softer sediment bottom beyond this range, whereas the modeling assumes a uniform low-loss bottom for the entire REA TL track.

An understanding of the magnitude of the improvement when using measured versus historical bathymetry and sound speeds is of interest. Accordingly, the Bellhop model was used to compare incoherent TL for the measured sound speed profile with bathymetry from the GSC dataset, and incoherent TL for the sound speed profile contained within the WADER32 dataset together with the measured bathymetry. These are also shown in Figure 11 as the green and blue lines respectively. The RMS model-data difference is 5.3 dB for the measured sound speed profile and GSC bathymetry, and 5.6 dB for the measured bathymetry and historical sound speed profile. As one might expect, these are slightly worse than the 4.8 dB for the measured environment, and better than the 6.2 dB for historical data alone.

Finally, in order to determine the possible effect of an unknown bottom composition (for example, if FFCPT measurements had not been available), a comparison of measured data to modeled transmission loss was conducted using a high-loss bottom (MGS bottom province 7). Model runs were conducted for this high-loss bottom (which has a -23 dB reflection coefficient for all angles at 1 kHz), with both historical (red line) and measured bathymetry and sound speed profiles (blue line). The result for the deep area is shown in Figure 12. The soft bottom results in erroneously high values of TL for any bottom-interacting path. The very large error in these cases highlights the requirement for environmental assessment. Without proper characterization of the seabed, the transmission loss and therefore effective sonar range could vary enormously even for short ranges.

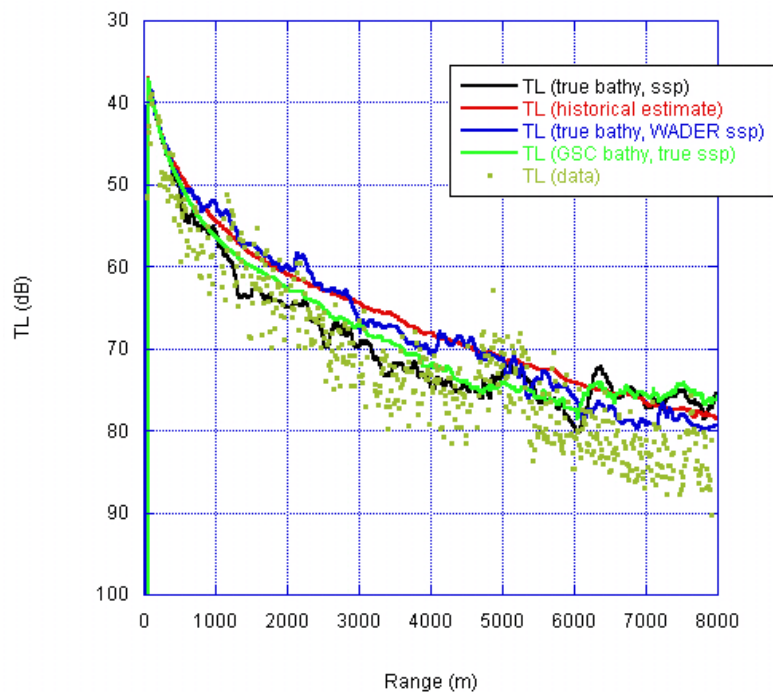


Figure 11: Comparison of Modeled Incoherent Versus Measured Transmission Loss with Varying Environments – Deep Area of TL Run.

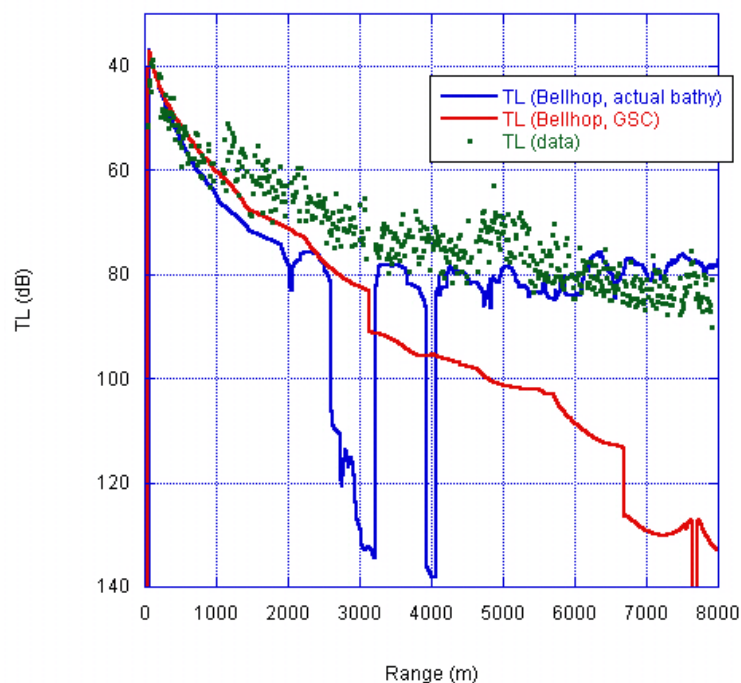


Figure 12: Comparison of Modeled Incoherent Versus Measured Transmission Loss – Deep Area of TL Run (With Soft Bottom).

Conclusion

The Moving Vessel Profiler (MVP) and the Free Fall Cone Penetrometer (FFCPT) have been jointly developed and integrated as an underway geotechnical measurement system. The system has been used at vessel speeds of 4-8 knots by the Canadian Navy in research trials and has proven itself to be a tremendously efficient system to collect sediment geotechnical data and water column speed of sound profiles. Use of this package as a Rapid Environmental Assessment (REA) tool for marine naval operations has the potential for improving the wealth of ground truth data that can be collected with minimal impact on traditional operations.

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